A Topology Optimization Interface for LS-Dyna

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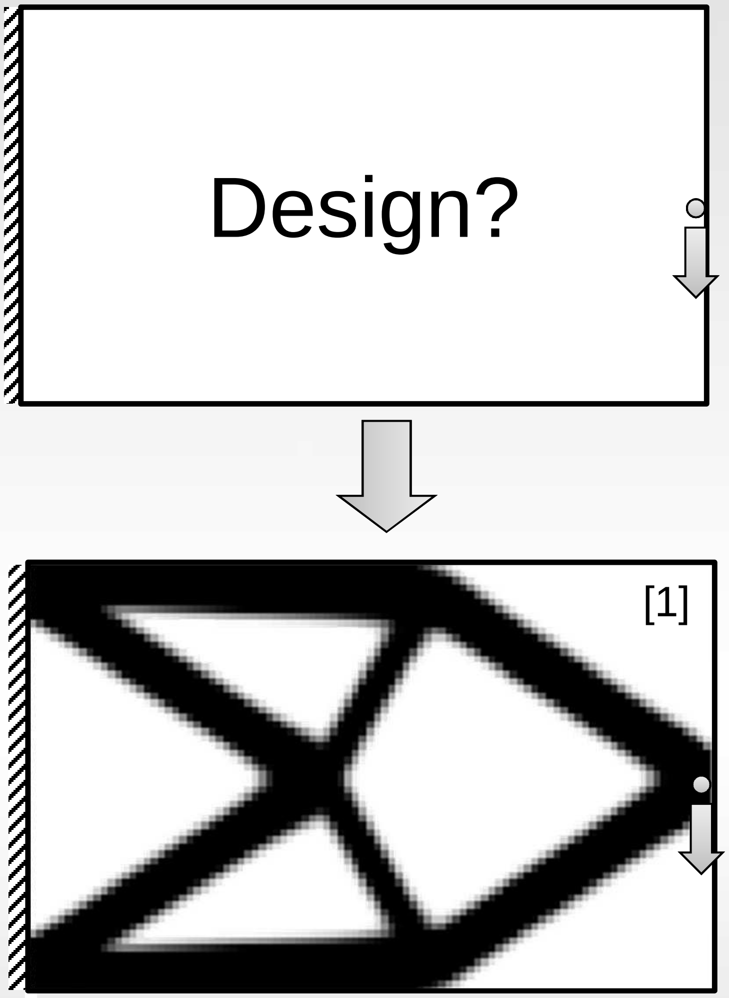
- **Introduction**
- **Implementation**
- **Application of Topology Optimization**
- **Summary**

Structural optimization

- Sizing / Thickness
- Shape
- **Topology**



Goal of topology optimization

- Make optimal use of material for a given design space
- Find a concept design

Benefits

- Save weight and material
- Shortening of design cycles

[1] O. Sigmund O. A 99 line topology optimization code written in Matlab. Structural and Multidisciplinary Optimization 21(2):120–127, 2001.

Application of topology optimization:

- Available in commercial software
- Mostly limited to linear or slightly non-linear problems

Topology optimization of crash structures

- Difficult to derive sensitivity information
- Approached by LS-TaSC [2,3,4]

Research directions:

- Multi-disciplinary problems
- More globally optimal solutions

Problem: How to couple topology optimization algorithm to LS-Dyna?

→

Solution: Develop interface between optimizer and LS-Dyna

[2] Roux, W.: "Topology Design using LS-TaSC™ Version 2 and LS-DYNA", 8th European LS-DYNA Users Conference, 2011
[3] Goel T., Roux W., and Stander N.: "A Topology Optimization Tool for LS-DYNA users: LS-OPT/Topology", 7th European LS-DYNA Users Conference, 2009.
[4] Patel, N. M.: "Crashworthiness Design using Topology Optimization", PhD thesis, University of Notre Dame, 2007

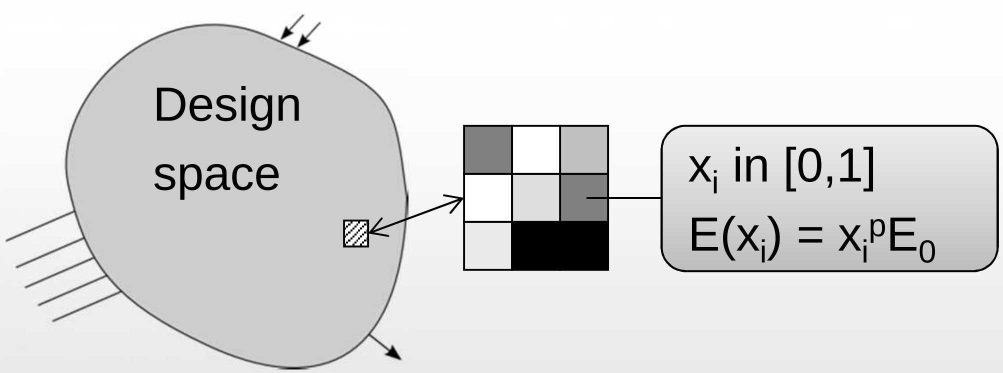
Interface requirements:

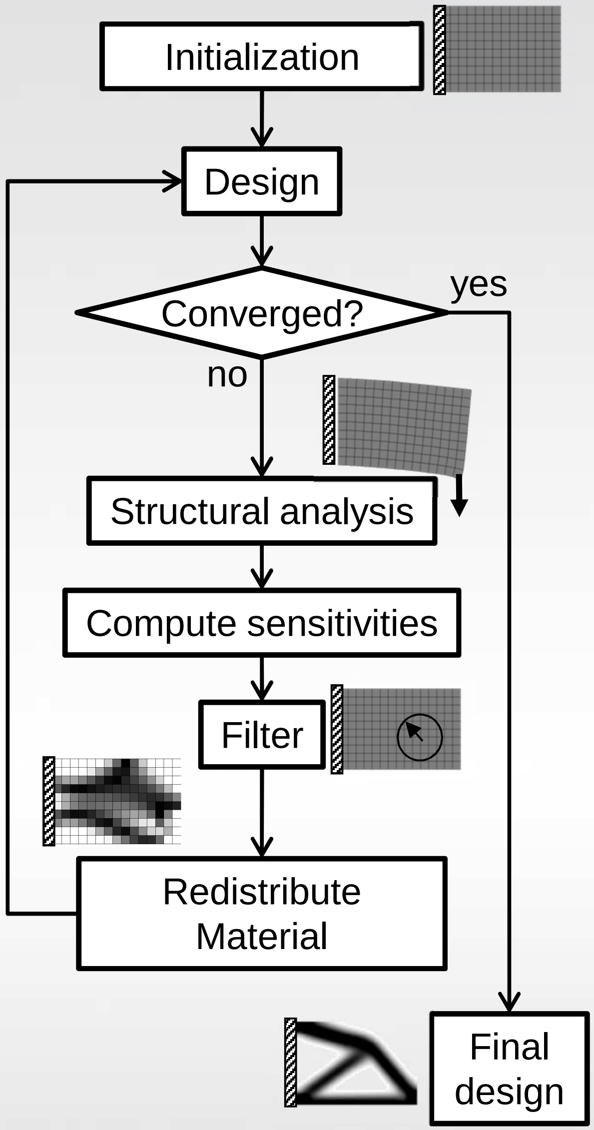
- Facilitate implementation of existing algorithms
- Flexibility to develop novel methods

Commonly approach to topology optimization

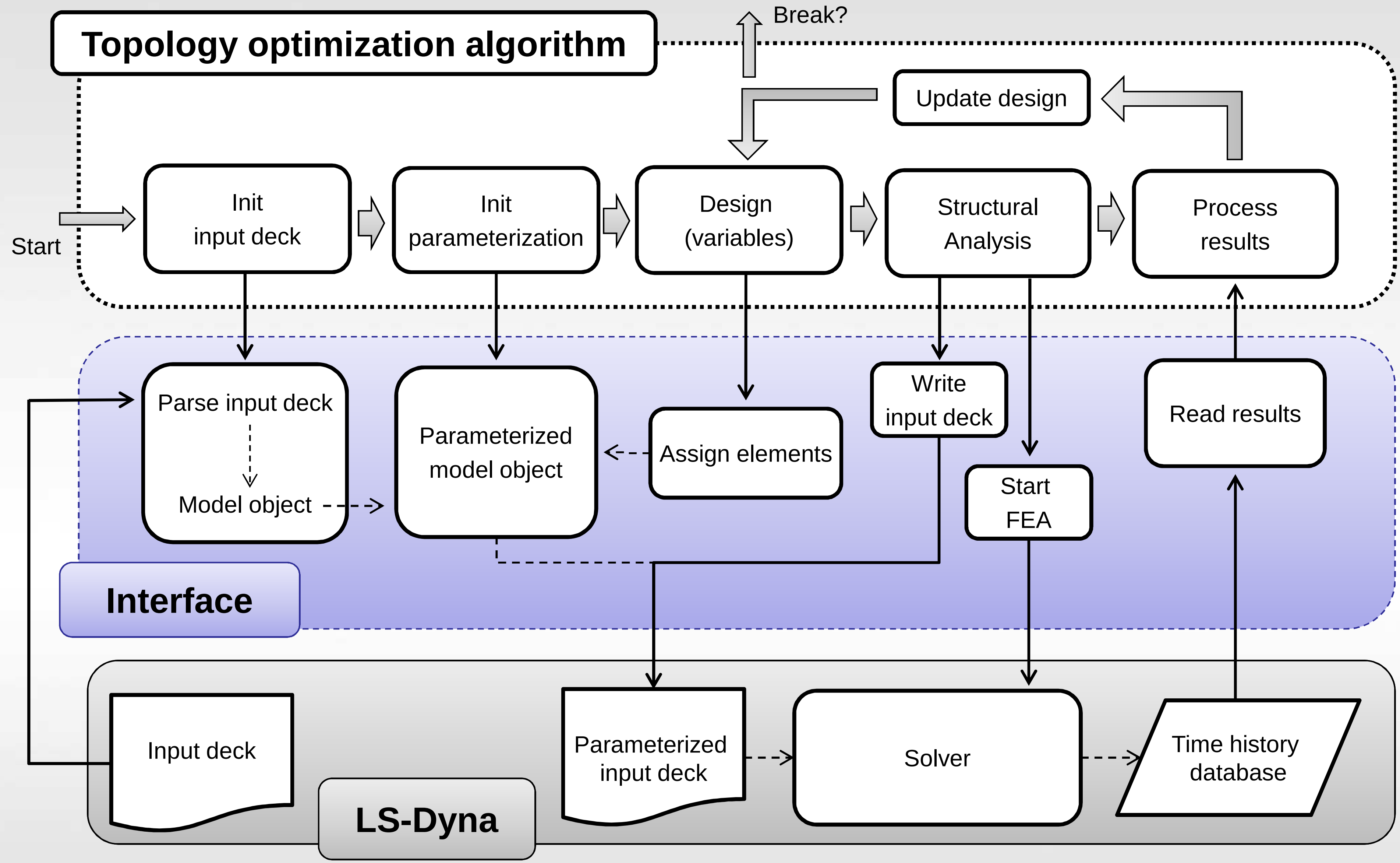
- Every finite element is assigned a density variable
- Material is redistributed iteratively, based on sensitivities
- Material properties are interpolated:

  Solid Isotropic Material with Penalization (SIMP) [5]



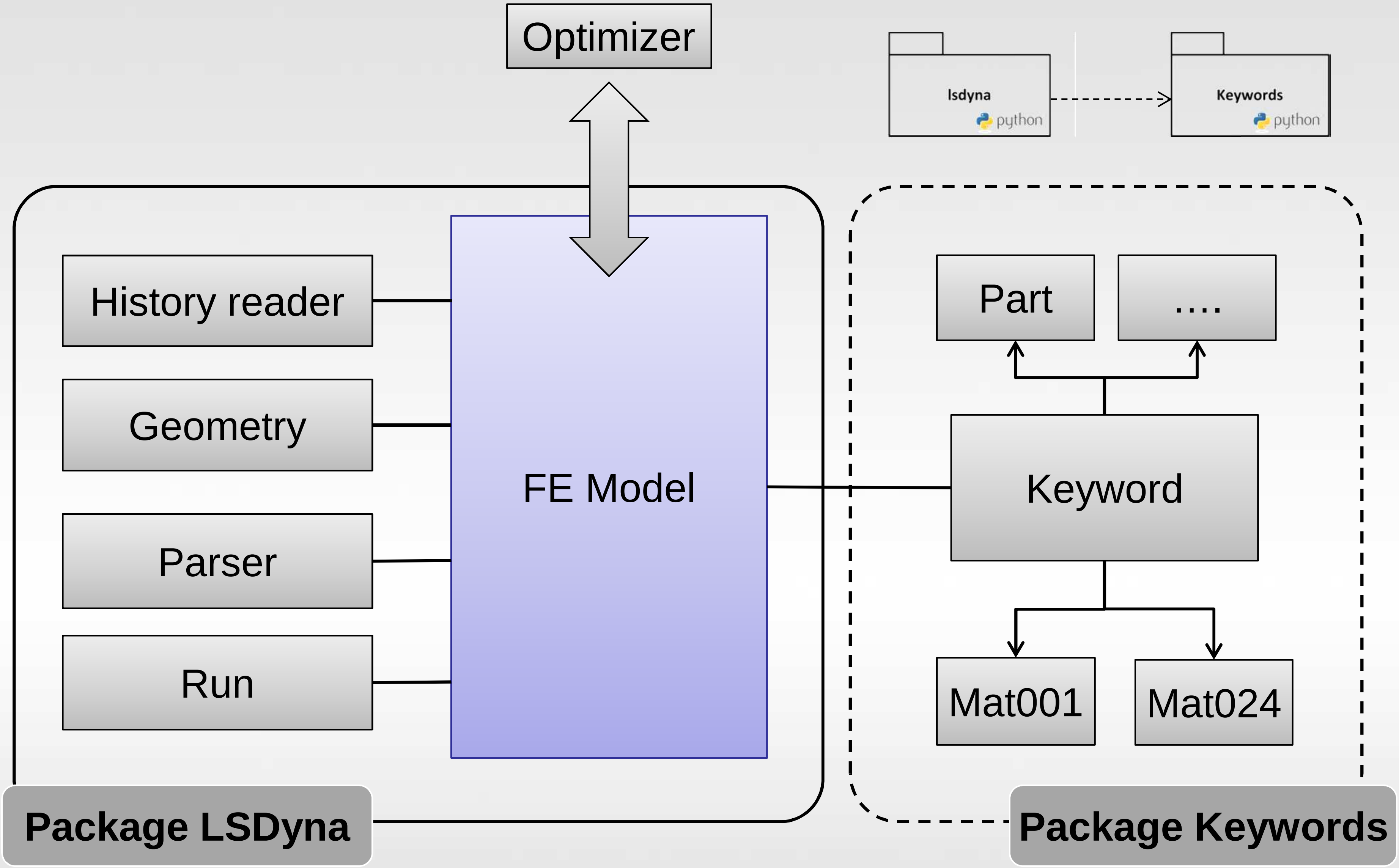


[5] Bendsoe, M.P., Sigmund, O., Topology Optimization, Theory, Methods and Applications, *Springer*, 2nd Ed., 2004.



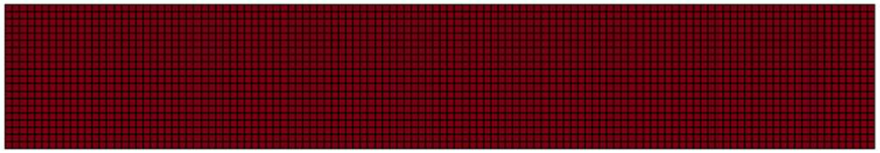
Topology optimization algorithm
Break?
Update design
Start
Init
input deck
Init
parameterization
Design
(variables)
Structural
Analysis
Process
results
Parse input deck
Model object
Parameterized
model object
Assign elements
Write
input deck
Start
FEA
Read results
Interface
Input deck
Parameterized
input deck
Solver
Time history
database
LS-Dyna

Implementation Overview



Material Parameterization

```python
import lsdyna

# declare FEModel object
femodel = lsdyna.FEmodel()
femodel.initInputDeck('model.key', [1])
```



Original input deck

```
*MAT_ELASTIC
        1 2.7000E-9  1.000000  0.330000     0.000     0.000
```

```
femodel.initInputDeck('model.key', [1])
```

```
# Parameterize the femodel
femodel.parameteriseMaterial('lin', 100)
```

```
*MAT_ELASTIC
$# copy of material 1, scaled by factor 0 for normalized density range [ 0.    0.01]
        2  2.700-09  1.000-10  3.300-01
*MAT_ELASTIC
$# copy of material 1, scaled by factor 0.01 for normalized density range [ 0.01  0.02]
        3  2.700-09  1.000-02  3.300-01
*MAT_ELASTIC
$# copy of material 1, scaled by factor 0.02 for normalized density range [ 0.02  0.03]
        4  2.700-09  2.000-02  3.300-01
                                        :
```

Material Parameterization

```
import lsdyna

# declare FEModel objec
femodel = lsdyna.FEmodel()
femodel.initInputDeck('model.key', [1])
```

*ELEMENT_SHELL

1	1	12	342	346	345	0	0	0	0
2	1	13	347	350	343	0	0	0	0
3	1	14	351	354	348	0	0	0	0

:

```
# Parameterize the femodel
femodel.parameteriseMat
```

*ELEMENT_SHELL

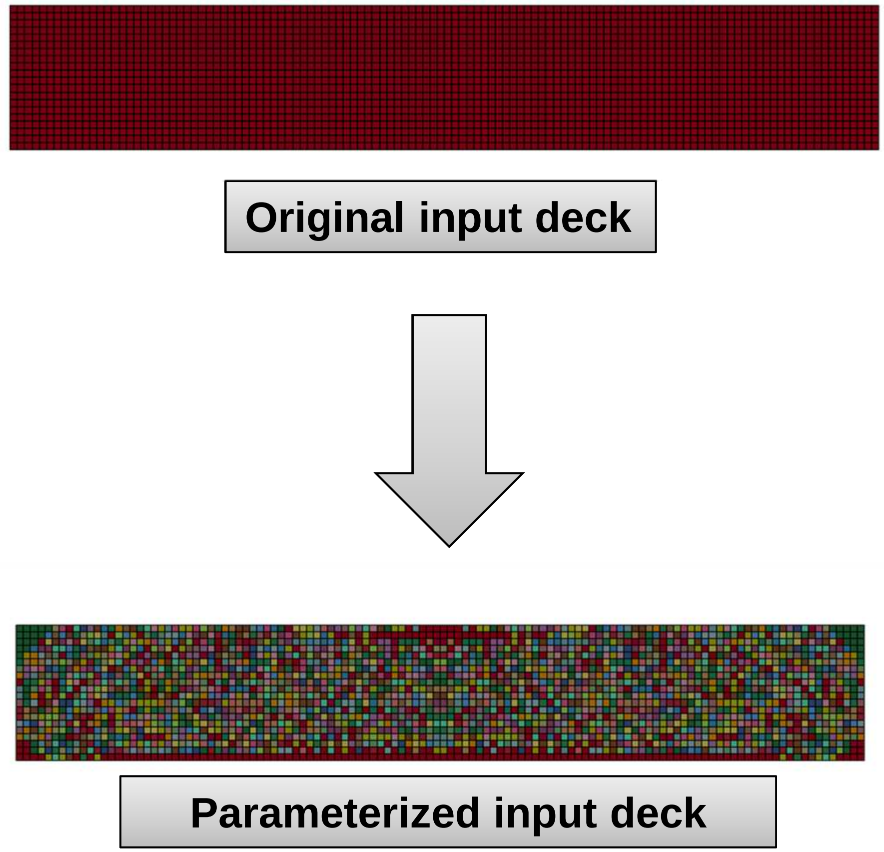
1	93	12	342	346	345	0	0	0	0
2	87	13	347	350	343	0	0	0	0
3	91	14	351	354	348	0	0	0	0

```
# Do some optimization

# Assign density values to the elements
femodel.writeDesignVariables(designVariables)

# Create an ls dyna Input deck
run = femodel.createRun([…])
femodel.createInputDeck(run)
```

```
import lsdyna

# declare FEModel object
femodel = lsdyna.FEmodel()
femodel.initInputDeck('model.ke
```

```
# Parameterize the femodel
femodel.parameteriseMaterial('
```

```
# Do some optimization […]

# Assign density values to the
femodel.writeDesignVariables(de

# Create an ls dyna Input deck
run = femodel.createRun([…])
femodel.createInputDeck(run)
```

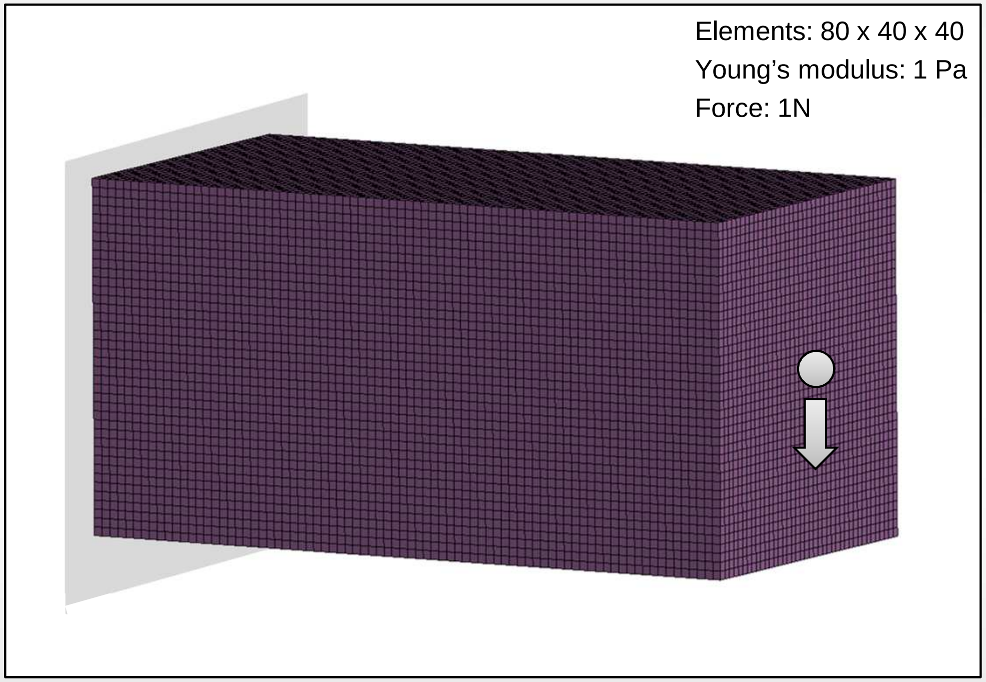


Example 1

First target:

- Implement standard algorithm [1]
- Use interpolation scheme

⇨ SIMP with optimality criteria update for stiffness optimization

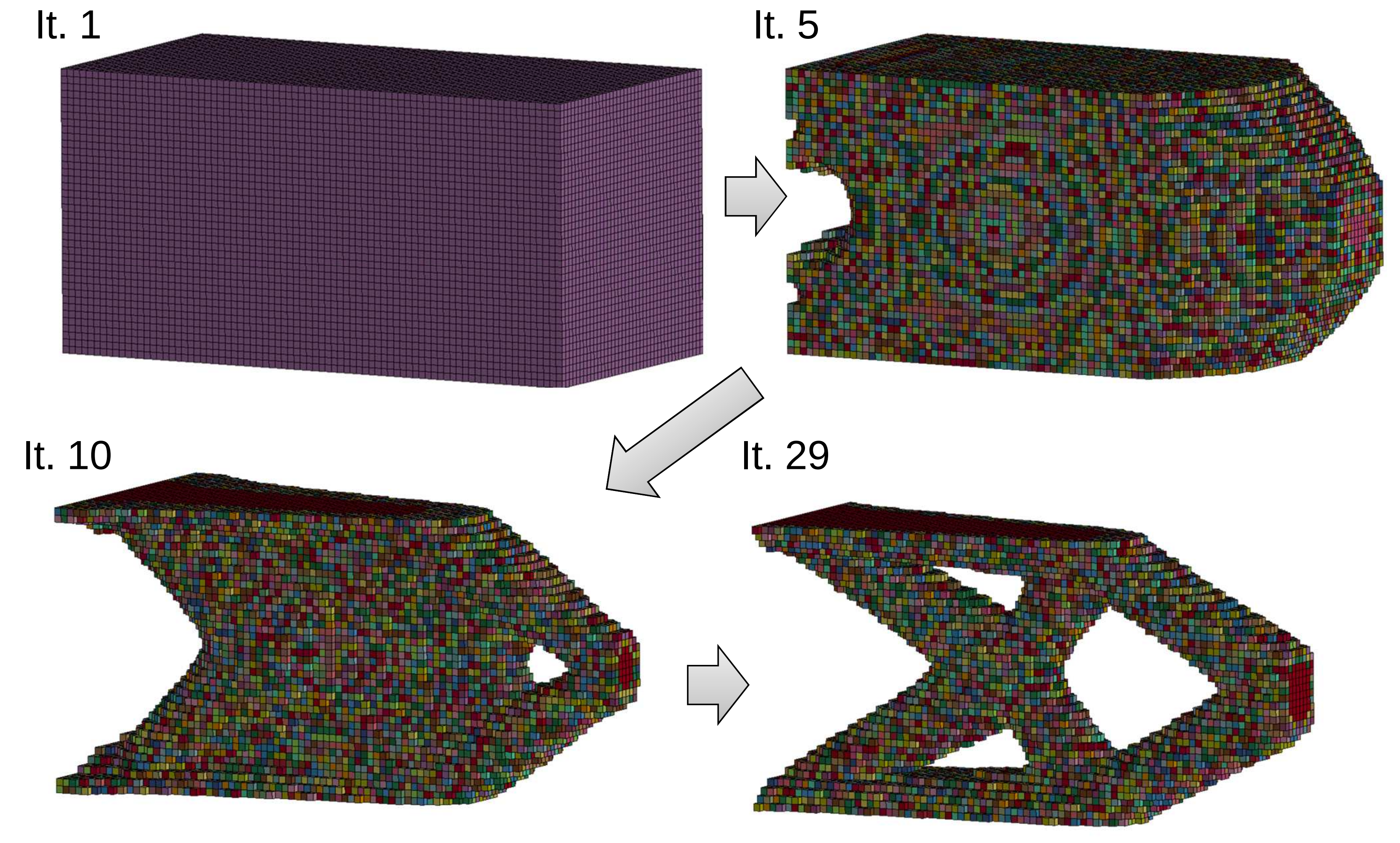


Test case:

- Short 3D cantilever
- 10% volume fraction
- One static load applied
- 128,000 solid elements
- Analysed with LS-Dyna implicit solver

[1] Sigmund, O. A 99 line topology optimization code written in Matlab. *Structural and Multidisciplinary Optimization* 21(2):120-127, 2001

Example 1 Result



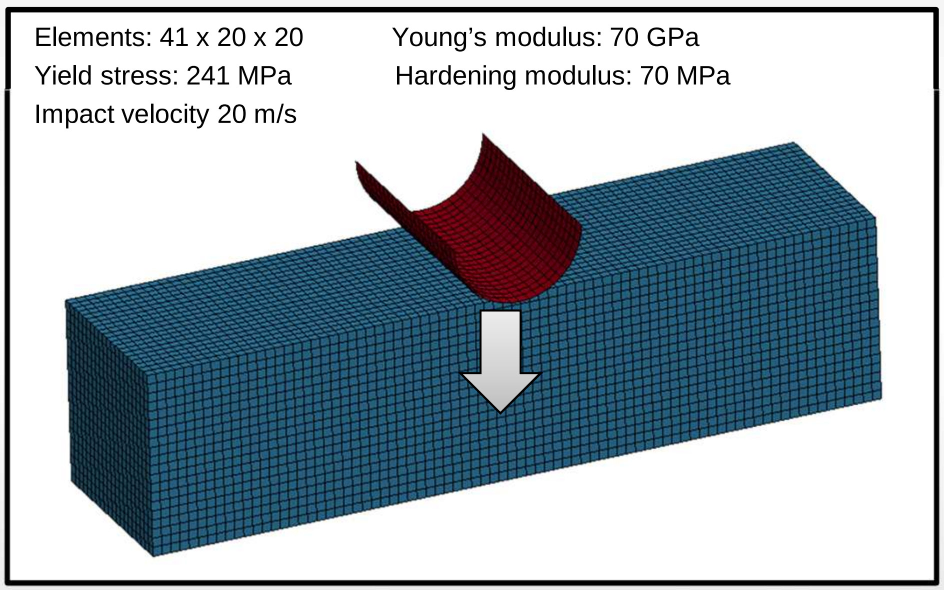
Example 2

Second target:

- Tackle optimization of energy absorbing structures

Bi-directional evolutionary structural optimization (BESO) [5]

- Elements are assigned a heuristic “sensitivity number”
- No interpolation, complete elements are removed or added

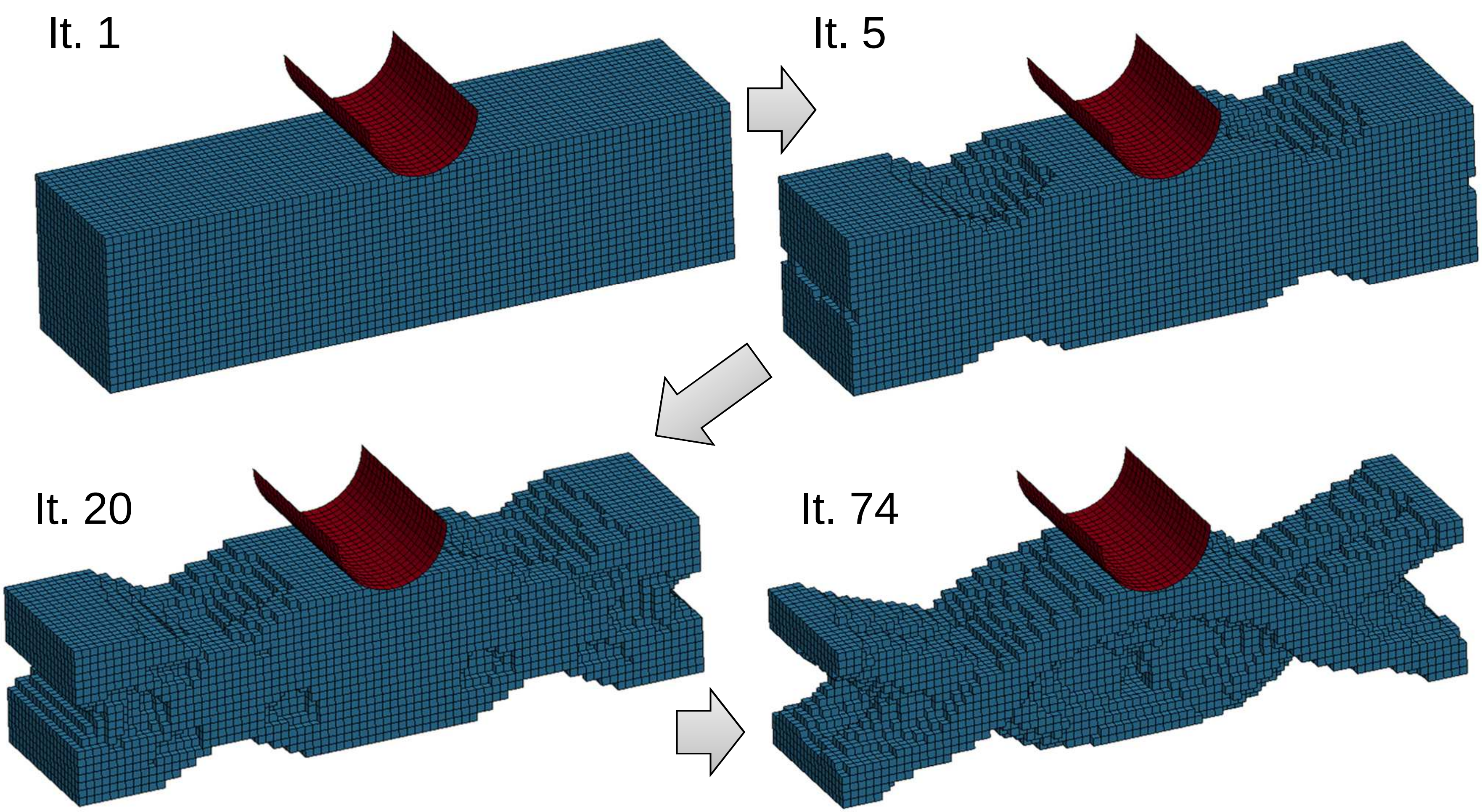


Test case:

- Pole impacting a beam, fixed on both sides
- Piecewise linear-elastic plastic material model
- 50% volume fraction

[5] Huang, X., Xie, Y.M., Lu, G. Topology optimization of energy absorbing structures. *International Journal of Crashworthiness* 12(6):663-75. 2007

Example 2 Result



Target: Research of topology optimization of non-linear problems

⇨ Necessity for coupling of LS-Dyna and optimizer

Interface Summary

- Parsing
- Parameterization
- Creation of input deck
- **Application:** Minimize compliance, maximize energy absorption

Future directions

- Extend for more material cards, ESL method (Interface)
- Tackle multi-disciplinary problems (Optimization)

Thank you for your attention!

Appendix: Class Structure Implementation